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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Strong Wind and Vertical Wind Shear Above 30 km

ARTHUR J. KANTOR

OFFICE OF AEROSPACE RESEARCH

United States Air Force

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Abstract

Strong wind and vertical wind shear must be considered for design and operation of vehicles that will either operate in or penetrate the upper stratosphere and mesosphere. Global extremes of these atmospheric parameters are estimated in this report for altitudes above 30 km. For the Northern Hemisphere estimated 90, 95, and 99% winds, related to the windiest months and locations, are provided for altitudes between 30 and 80 km. Speed increases up to about 55 km and appears to decrease thereafter up to at least 75 or 80 km in November, December, and January. The 99% winds can be expected to approach 215 mps near 55 km at certain locations between latitudes 35 and 60°N. For the Southern Hemisphere 90, 95, and 99% winds are provided for altitudes between 30 and 60 km. The 99% winds reach roughly 200 mps near 55 km. Since estimates for the Southern Hemisphere are not necessarily representative of either the windiest month or location, results are uncertain and speeds probably will be somewhat larger than indicated. For the same percentiles, 1-km thick vertical wind shears have been estimated for altitudes between 30 and 70 km. Shears generally increase, and maximum values tend to move equatorward with altitude.

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Strong Wind and Vertical Wind Shear Above 30km

1. INTRODUCTION

Strong wind and vertical wind shear (change in horizontal wind velocity with altitude) have long been meteorological problems affecting conventional aircraft flight and missile design and operation in the upper troposphere and lower stratosphere. They must also be considered for design and operation of vehicles that will operate in or penetrate the upper stratosphere (above 30 km) and mesosphere. Large shears, for example, produce forces on aerospace vehicles which alter their attitude, pointing them in the wrong direction and resulting, possibly, in excessive heating due to unplanned angles of attack. Large shears can also be significant during staging above 30 km, that is, separation of a booster from its main vehicle on ascent, since flight control of aerodynamic vehicles may be lost temporarily during this maneuver (Sissenwine, 1968). Consequently, certain extreme wind and wind shear values above 30 km will be critical for the design and operation of aerospace systems, present and future. Critical values will differ, however, according to the particular design of the individual aerospace vehicle.

In this report 90, 95, and 99% winds and wind shears (values which will be exceeded 10, 5, and 1% of the time, respectively) are provided for altitudes between 30 and 80 km. These winds have been derived from data primarily at locations in the Northern Hemisphere, although percentiles have also been esti-

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mated for the Southern Hemisphere, based on a small number of observations from six stations between latitudes 6 and 78°S. In the Northern Hemisphere, percentiles have been related to the windiest month and region.

Wind shears, also provided as 90, 95, and 99% values, must be considered as only very rough first estimates. They have been based on scattered data at a few locations, primarily in the Northern Hemisphere, for which observations are sufficiently detailed to permit estimation of 1-km shears between 30 and 70 km. Data for days and months were also pooled due to the restricted sample size. Consequently, shear results could not be related necessarily to either a month or location of maximum shears.

2. OBSERVATIONS

Data available for this report consisted of wind observations above 30 km from more than 30 Northern Hemisphere locations stretching from approximately 9 to 77°N, and described in the Data Reports of the Meteorological Rocket Network (MRN) Firings. Observations encompassing up to eight years of winds at several of the North American stations were derived from a variety of sensors, but primarily from parachute-borne instruments launched by rockets.

The six Southern Hemisphere stations for which wind data were available for use are listed below:

Table 1. Stations in the Southern Hemisphere

Station	Location	
Natal, Brazil	6°S,	35°W
Ascension Island	8°S,	14°W
Chamical, Argentina	30°S,	66°W
Woomera, Australia	31°S,	136°E
Mar Chiquita, Argentina	38°S,	67°W
McMurdo Sound, Antarctica	78°S,	167°E

Again, rocket-launched parachutes were the major wind sensors, except at Woomera where rocket grenades provided the bulk of the data for the years between 1957 and 1963.

Useable data for the wind shear portion of this study were more severely limited than for winds since the aerodynamics of parachutes, the most popular sensor, are such that much of the difference between wind vectors in adjacent layers may be due to gliding or sailing of the parachute. Also, altitude intervals for which data are provided by chute-borne sensors are too coarse for determination of 1-km or smaller vertical wind shears. As a result, wind shear estimates have been based on only a few series of detailed FPS-16 radar tracked ROBIN (an inflated 1-m plastic sphere) sensors beginning in 1960 at the following six stations:

Table 2. Number of Soundings and Shears at ROBIN Tracking Stations

Location		Number of ROBIN Soundings	Number of 1-Km or 3000-ft Shears
Ascension Island	(8°S)	32	1296
Kwajalein Island	(9°N)	11	273
Cape Kennedy, Fla.	(28°N)	21	746
Eglin AFB, Fla.	(30°N)	161	5044
Holloman AFB, N. M.	(33°N)	19	509
Wallops Island, Va.	(38°N)	14	397

3. TECHNIQUE

The first objective of this study is to provide information on 90, 95, and 99% winds above 30 km relative to the windiest months and locations. Consequently, based on the observations described above, vertical cross sections of mean monthly zonal (east-west) and meridional (north-south) winds were constructed for these altitudes in the Northern Hemisphere. Mean monthly wind vectors were computed from the estimated component winds, and the resulting wind vectors were found to be largest during November, December, and January and between latitudes 35 and 60°N. Mean monthly cross sections of the component winds between 30 and 60 km, the layer with most plentiful data, are shown for these months in Figure 1 through 3. Standard deviations of the component winds for these months, based on data from appropriate MRN Data Reports for locations within the region 35 to 60°N, were used to estimate the vector standard deviations of the monthly winds for the windiest locations in the Northern Hemisphere. Using the vector means and their associated vector standard deviations and assuming a circular normal approximation, the 90, 95, and 99% scalar wind speeds were calculated with the nomograph provided by Crutcher (1959). The

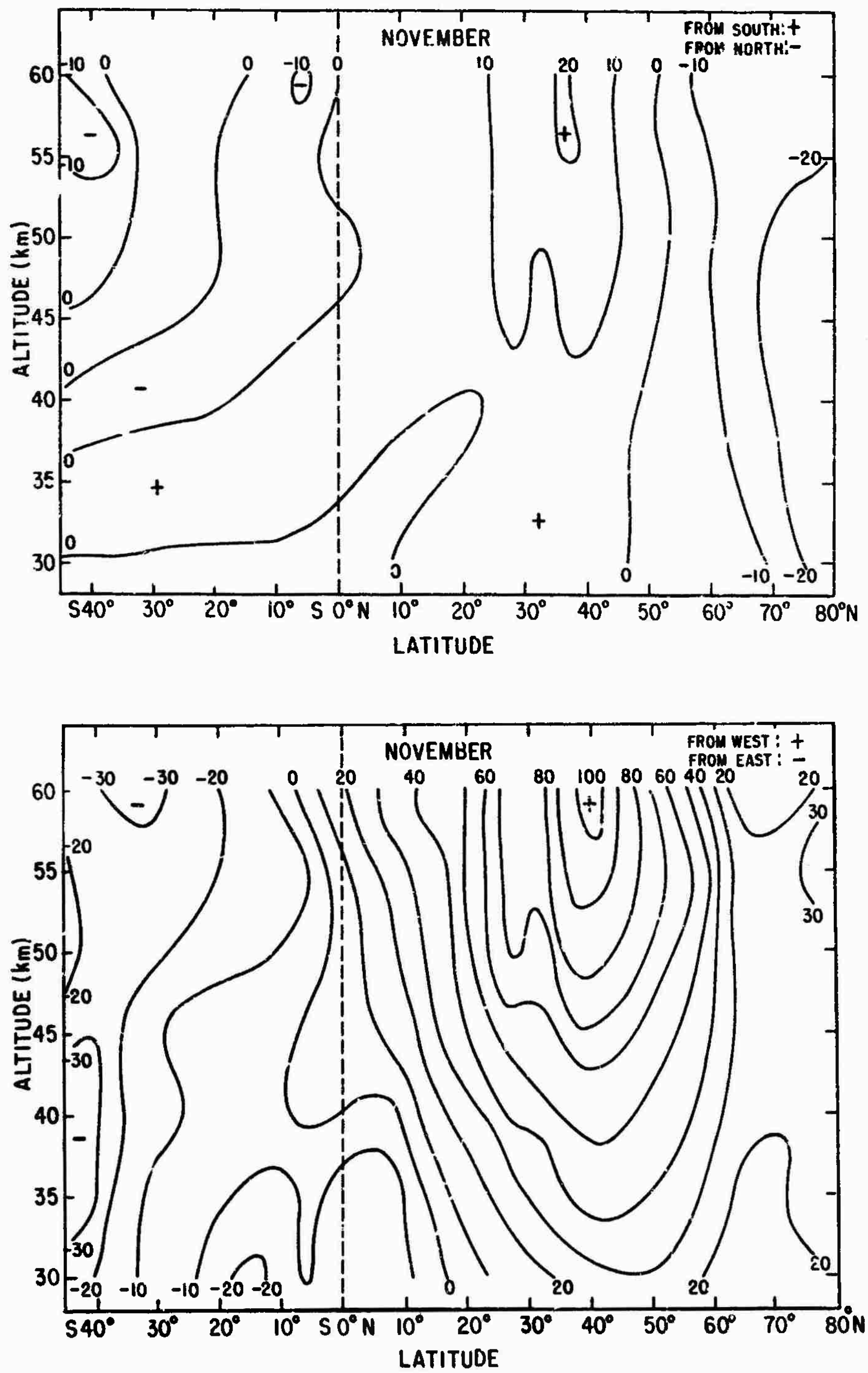

Figure 1. Mean Wind Components (mps) for November

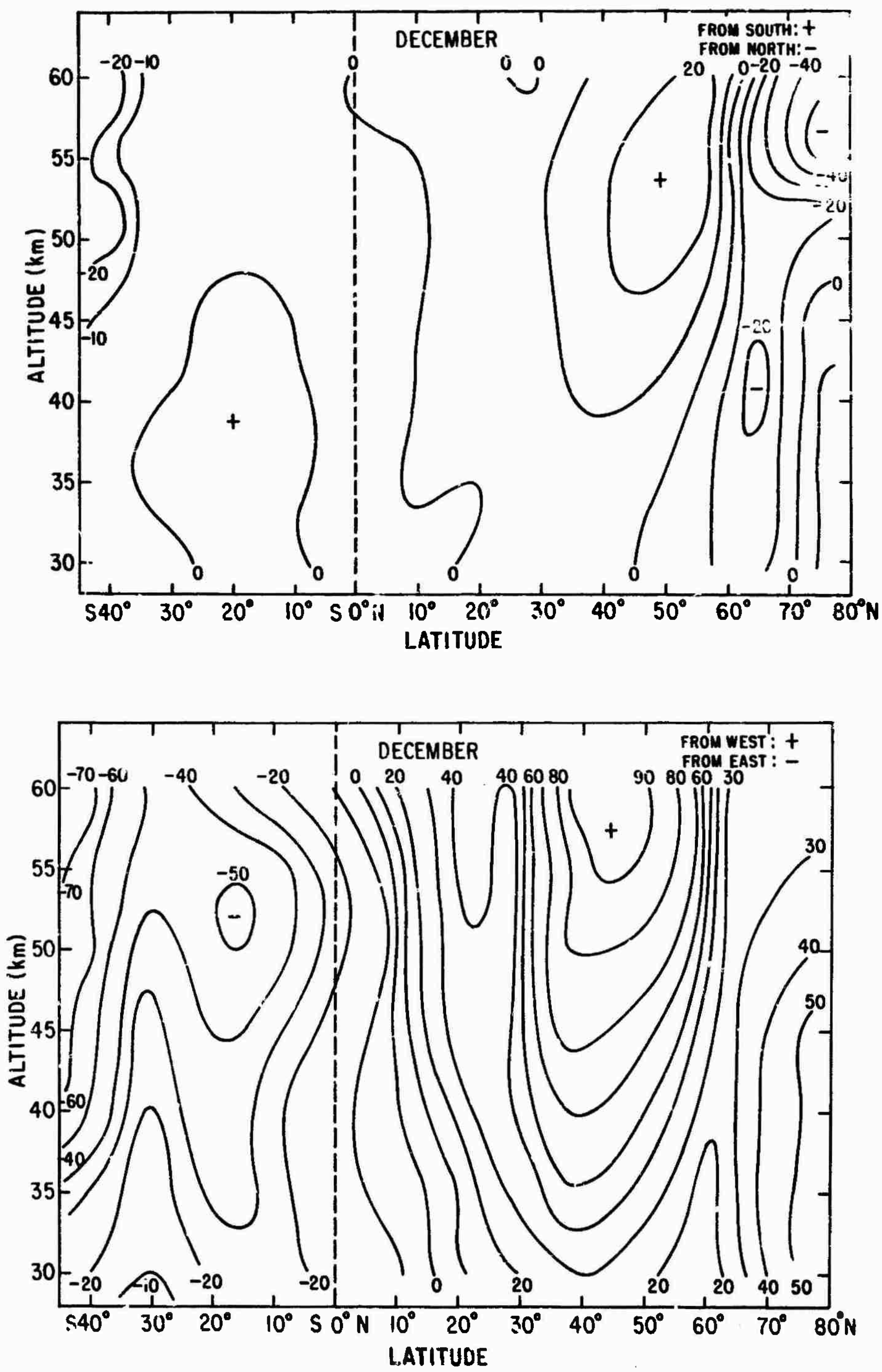

Figure 2. Mean Wind Components (mps) for December

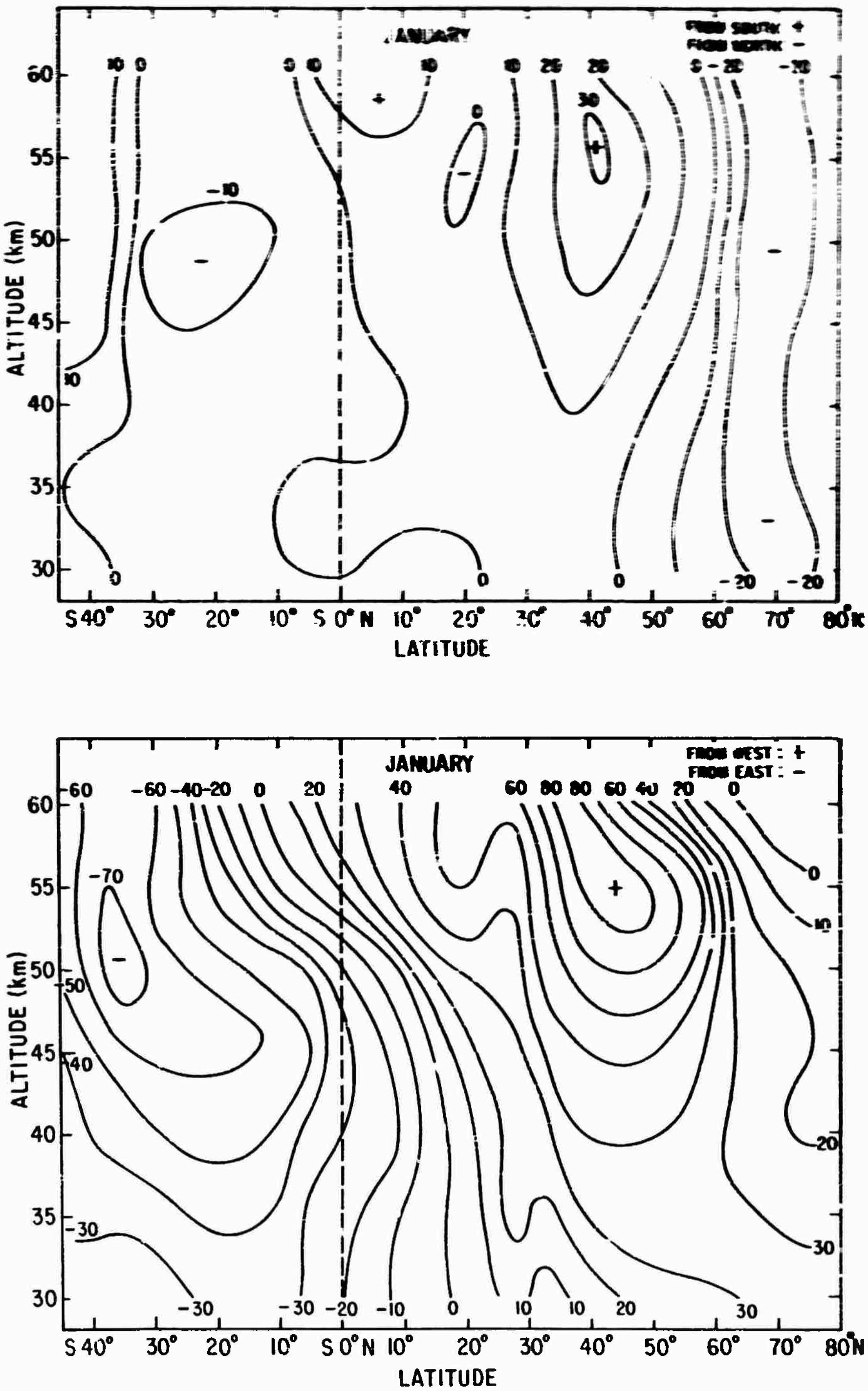

Figure 3. Mean Wind Components (mps) for January

largest resulting 90, 95, and 99% scalar winds (mps) are shown in Table 3a for 2-km intervals up to 62 km and for 5-km intervals between 65 and 80 km.

Since wind data above 30 km in the Southern Hemisphere were limited to a small number of observations at six locations, only rough estimates of 90, 95, and 99% winds could be made and compared with those for the Northern Hemisphere. Although observations were insufficient for construction of definitive equator-to-pole vertical cross sections, available data suggested strongest mean monthly winds between latitudes 35 and 45°S during the Southern Hemisphere winter months, May, June, July, and August. Observations for specific locations were so severely limited that component means and standard deviations had to be estimated by pooling the data for these four months at Mar Chiquita, the windiest Southern Hemisphere location for which data were available. For this limited sample, the population standard deviations were estimated by using N-1 rather than N observations. Vector means and vector standard deviations then were calculated as described earlier for the Northern Hemisphere. Table 3b depicts resulting 90, 95, and 99% scalar winds (mps) by 2-km altitude intervals from 30 to 60 km.

The second objective of this report is to provide information on the occurrence of large vertical wind shears at altitudes above 30 km. Wind shear data for the six stations noted earlier have been summarized recently (Salmela and Sissenwine, 1969) and frequency distributions of 1-km and 3000-ft (914 m) shears were provided for altitudes between 30 and 70 km. Frequency distributions of these shears were used to estimate 90, 95, and 99% 1-km shears between 30 and 70 km and for each of the four 10-km altitude intervals between 30 and 70 km at every location. The shear data were ordered from the smallest values to the largest and plotted on probability paper using Kimball's (1960) suggested formula:

$$P_i = \frac{i - 3/8}{n + 1/4} \quad , \tag{1}$$

where i is the order and n represents the number of observations. Curves were drawn through the derived points to provide 90, 95, and 99% 1-km shears at all six stations between 30 and 70 km and for the four 10-km layers between 30 and 70 km.

Frequency distributions of these shears, provided for consecutive 1-km or 3000-ft layers at every location, have also been provided by Salmela and Sissenwine (1969) for all possible (overlapping) 3000-ft intervals at Cape Kennedy. This had the effect of increasing the sample size at Cape Kennedy by about a factor of three. It also produced larger shear values which were not

Table 3. Scalar Wind Speed (mps) ≥ 90, 95, and 99% of the Windiest Period and Location

a. Northern Hemisphere

Alt (km)	Percentile (%) 90%	95%	99%
30	65	72	83
32	76	85	99
34	88	98	115
36	99	110	130
38	110	122	143
40	121	134	156
42	136	150	175
44	151	166	194
46	159	175	206
48	161	178	209
50	163	180	212
52	165	182	214
54	166	184	215
56	162	180	210
58	152	168	195
60	146	158	180
62	144	155	175
65	140	151	169
70	133	145	165
75	115	126	145
80	114	125	145

b. Southern Hemisphere

Alt (km)	Percentile (%) 90%	95%	99%
30	58	63	72
32	64	70	80
34	71	[illegible]	88
36	84	92	105
38	100	108	123
40	117	125	141
42	130	138	154
44	136	145	162
46	145	154	171
48	157	165	184
50	162	171	190
52	170	180	200
54	170	180	200
56	163	173	192
58	152	160	178
60	150	159	175

necessarily included in the smaller, consecutive 3000-ft Cape Kennedy sample. The two sets of values and the ratios of the overlapping shears to consecutive shears are shown in Table 4.

Table 4. Cape Kennedy 3000-ft Vertical Wind Shears (sec^{-1}), 30-70 km

Percentile	Consecutive	Overlapping	Ratio
90	0.0129	0.0139	1.08
95	0.0154	0.0168	1.09
99	0.0248	0.0280	1.13

These average factors (1.08, 1.09 and 1.13) have been applied to appropriate percentiles of shear at all six stations, presumably providing more realistic estimates of 90, 95, and 99% wind shears, respectively.

4. WIND RESULTS

Estimated 90, 95, and 99% wind speeds up to 80 km, related directly to the windiest months and locations in the Northern Hemisphere, are shown in Table 3a. Speed (mps) increases up to roughly 55 km and appears to decrease thereafter up to at least 75 or 80 km. Although insufficient information is available, it is generally believed that values tend to increase again with altitude up to at least 120 km. As can be seen from the table, the 99% wind extreme can be expected to reach 215 mps at 54 km at the windiest locations which lie between latitudes 35 and 60°N and during the windiest months, November, December, and January.

For comparison, estimated 90, 95, and 99% wind speeds over the Southern Hemisphere are shown in Table 3b for altitudes 30 to 60 km. These winds (mps) appear to reach a maximum between 50 and 56 km, or approximately the same altitudes as for the Northern Hemisphere. For the percentiles provided, Southern Hemisphere values are generally somewhat smaller than Northern Hemisphere values, with the 99% winds attaining 200 mps between 52 and 54 km. However, the Southern Hemisphere estimates were based on only a small amount of pooled data at six widely scattered locations, so that they are not necessarily representative of either the windiest month or location. As a result, the 90, 95, and 99% values may be even stronger than indicated, and, although at roughly the same altitude intervals as in the Northern Hemisphere, the height at which maximum scalar wind speed occurs for the indicated percentiles is uncertain.

5. SHEAR RESULTS

Estimated 90, 95, and 99% 1-km vertical wind shears and the latitudes at which they occur are shown below in Table 5.

Table 5. Estimated 1-km Vertical Wind Shears (sec^{-1})

Percentile	30-70 km	60-69 km	50-59 km	40-49 km	30-39 km
90	0.035(9°N)	0.076(9°N)	0.019(9°N)	0.017(33°N)	0.015(38°N)
95	0.058(9°N)	0.085(9°N)	0.024(30°N)	0.021(33°N)	0.018(38°N)
99	0.110(9°N)	0.121(9°N)	0.042(30°N)	0.046(33°N)	0.059(38°N)

The 90, 95, and 99% 1-km shears generally increase with increasing altitude up to at least 70 km. For these percentiles, the latitude (or location) of maximum shears tends to move equatorward with increasing altitude. For the entire 30 to 70 km layer, the largest 1-km shears seem to occur at low latitudes. The above estimates, however, represent only very rough first approximations, since they have been based on just a few sporadic observations at the six locations described earlier. Although they are estimated from one sensor (ROBIN sphere), winds were not necessarily observed during the same months or years at any of the stations, nor could derived values be related to either a month or location of maximum shears.

6. LIMITATIONS

Characteristics of the rocketsonde parachute, the primary wind sensor for altitudes between 30 and 80 km, are such that rms errors in wind speed are roughly 4 mps (Meteorological Working Group, 1965). According to Engler's (1965) study, rms wind errors for the ROBIN sphere range from about 1/2 mps below 50 km to 3 mps between 60 and 70 km (see Table 6). Other sensors include grenades and metallic chaff which provided data from a relatively small number of locations in North American and Australia.

Estimated vertical wind shears, based on the ROBIN measurements mentioned earlier, were derived directly from the vector winds and differences between 1-km vectors. Consequently, shear accuracy depends upon the errors involved in obtaining the vector winds. If, in determining wind shear, the wind vector errors are assumed to be uncorrelated, the rms error in shear can be estimated as $1\sqrt{2}$ times that of the vector errors. The rms errors in wind (Engler, 1965) and wind shear are shown in Table 6 below.

Table 6. Rms Errors for ROBIN Winds and Wind Shears

	60-70 km	50-60 km	50 km
Wind (mps)	3.2	1.3	0.54
1-km Shear (sec^{-1})	0.0045	0.0018	0.0008

Comparison of values in Table 5 with those in Table 6 reveals that errors involved in determining 90, 95, and 99% shears, or any large shear appear insignificant. For the ROBIN Sphere at these percentiles, rms errors apparently are no larger than roughly 1/10 the magnitude of the appropriate shear estimates.

7. CONCLUSIONS

Although specific wind and vertical wind shear values are provided in this report, results must necessarily be considered preliminary, particularly with respect to shears and Southern Hemisphere winds. The following tentative findings are presented:

a. Estimated 90, 95, and 99% wind speeds between 30 and 80 km have been related to the windiest months and locations in the Northern Hemisphere. Winds increase up to roughly 55 km and appear to decrease thereafter up to at least 75 or 80 km. The 99% winds can be expected to reach 215 mps near 55 km between latitudes 35 and 60°N and during the windiest months, November, December, and January.

b. The 90, 95, and 99% wind speeds between 30 and 60 km have also been estimated for the Southern Hemisphere. They appear to approach a maximum at altitudes between 50 and 56 km, with 99% speeds of approximately 200 mps. Calculated winds are usually somewhat smaller than those for the Northern Hemisphere. Southern Hemisphere estimates, however, must be considered uncertain since they have been based on a small number of pooled observations at six widely scattered locations and are not necessarily representative of either the windiest month or location.

c. One-km thick 90, 95, and 99% vertical wind shears, estimated for altitudes between 30 and 70 km, generally increase with altitude, and maximum values tend to move equatorward. These shear results represent only very rough first approximations, since they have been based on just a few series of ROBIN falling sphere observations at six scattered locations. The data used were not necessarily provided for the same months or years at any of the stations, nor could derived values be related to either a month or location of maximum shears.

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OFFICE OF AEROSPACE RESEARCH
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